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6. AUTHORS
Yong-Hang Zhang

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
Arizona State University
ORSPA
P.O. Box 876011
Tempe, AZ 85287 -6011

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14. ABSTRACT
This DURIP project focuses on developing a measurement setup for the study of the carrier dynamics in Ga-free InAs/InAsSb type-II superlattices (T2SL) based infrared photodetectors. Ga-free InAs/InAsSb T2SLs offer great advantages for MWIR and LWIR laser and detector applications due to their broad bandgap tunability and material uniformity. We have been supported by a recent ARO MURI program to study the defects and their mitigation in antimony-based T2SLs, and by a joint program from AFOSR and ARO to demonstrate novel optically-addressed

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Report Title

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

1. Title: Carrier localization in InAs/InAsSb type-II superlattices
authors: Zhi-Yuan Lin, Shi Liu and Yong-Hang Zhang
conference name: SPIE DSS 2015
date: April 21th, 2015

2. Title: A real-time baseline correction method for time-resolved photoluminescence
authors: Zhi-Yuan Lin and Yong-Hang Zhang
conference name: SPIE optics + photonics 2015
data: August 12th, 2015

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

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Peer-Reviewed Conference Proceeding publications (other than abstracts):

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Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

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Received Paper

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Received Book

TOTAL:

Received	Book Chapter

TOTAL:

Patents Submitted

Provisional patent:
name: real-time baseline correction method for time-resolved photoluminescence
fill date: March 24th 2015

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
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Inventions (DD882)

Scientific Progress

See attachment

Technology Transfer

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US ARMY ACC-APG-RTP W911NF
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UU	UU	UU	UU	8	Yong-Hang Zhang
					19b. TELEPHONE NUMBER *(Include area code)* 480-965-2562

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The Final Report for the ARO DURIP Program

Electrical and Optical Characterization System for IR Photodetectors

Grant No.: W911NF-14-1-0446

Period 01/08/2014 to 31/07/2015

PI: Yong-Hang Zhang

Director, Center for Photonics Innovation

&

Fulton Entrepreneurial Professor, School of Electrical, Computer and Energy Engineering

Arizona State University

Tempe, AZ 85287

Tel: 480-965-2562

Fax: 480-965-0775

E-Mail: yhzhang@asu.edu

I. Project objective

This DURIP project focuses on developing a measurement setup for the study of the carrier dynamics in Ga-free InAs/InAsSb type-II superlattices (T2SL) based infrared photodetectors.

Ga-free InAs/InAsSb T2SLs offer great advantages for MWIR and LWIR laser and detector applications due to their broad bandgap tunability and material uniformity. We have been supported by a recent ARO MURI program to study the defects and their mitigation in antimony-based T2SLs, and by a joint program from AFOSR and ARO to demonstrate novel optically-addressed multicolor photodetectors and focal plane arrays.

II. Experimental systems upgrade

The transient signals from the T2SL samples, including optical signals and electrical signals, provide useful information for the understanding of the materials and devices. Time-resolved photoluminescence (TRPL) is a relatively traditional way to characterize the carrier lifetime in bulk material. We have developed a method that can significantly suppress the noise in our TRPL setup so as to make the measurement much more efficient. Furthermore, the transient electrical signal decays such as open circuit voltage decay and photocurrent decay in the photodetectors can offer more information about the carrier dynamics under the working conditions of the photodetectors. Experimental systems that can carry out the measurement for such transient electrical signals are also developed. In this DURIP program, four experimental systems are compiled or upgraded for the characterization of InAs/InAsSb T2SL materials and photodetector devices.

1. TRPL system

A previously used TRPL system was upgraded with new equipment and a Real-time Baseline Correction (RBC) method is developed, which make the measurement more efficient. As shown in Figure 1, the newly purchased equipment is in the blue dashed boxes, and the equipment used for the RBC modification of the experiment is marked using the red circles. The newly purchased equipment includes a fast HgCdTe (MCT) detector and a 1064 nm pulse laser. The new fast MCT detector has an effective area of 0.5 mm × 0.5 mm, 24 times larger than the old one. The larger effective area collects more photoluminescence (PL) and the signal intensity is enhanced. The new 1064 nm laser has a short pulse width of less than 1 ns, and a high pulse energy of 7 μJ, which enables the system to resolve the short lifetime of the samples with weak PL signals. The RBC method implants a chopper and a lock-in amplifier into the system and suppresses the noise by 2 orders of magnitude. The upgraded TRPL system can perform experiments with a higher cutoff frequency and a larger signal-to-noise ratio.

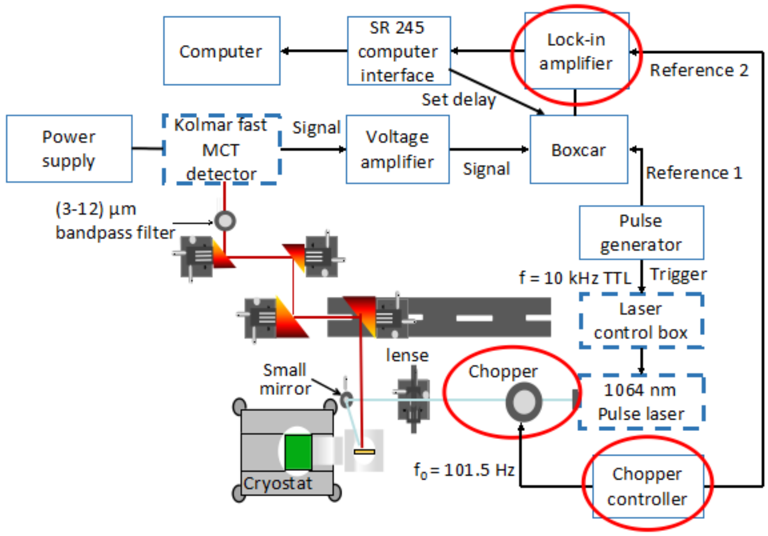

Figure 1. The block diagram of the upgraded TRPL system. The detector and laser are newly purchased. The chopper and lock-in amplifier are implanted to suppress the noise. After the upgrade, the system has a higher cutoff frequency and a larger signal-to-noise ratio.

2. Cryostat-based time-resolved electrical signal measurement system

In this system, the detector samples are wire-bonded and the electrical signals are extracted using copper wires, providing a cut-off frequency of 1 MHz. The samples in the cryostat can be cooled down to 8 K with a thermal shield and down to 12 K without the thermal shield for optical injection. Multiple lasers have been purchased and integrated into this system. With multiple lasers at different wavelengths, the system is capable of testing the behaviors of the device at different light absorbing conditions, providing useful information for the understanding of the device physics. This system can be used for both transient open circuit voltage measurements and transient photocurrent measurements.

Figure 2 shows the experimental setup using the 1064 nm pulse laser. The same RBC method is applied here to suppress the noise. Figure 3 shows the experimental setup using the 785 nm CW laser, which can be modulated electrically, generating a square wave of light. The decay tails of the rising edges and falling edges are as short as 5 µs. Figure 4 shows the experimental setup using the 3390 nm CW laser. This laser cannot be modulated electrically and therefore it has to be modulated by a chopper. Due to the finite size of the chopped laser beam, the rising time and falling time of the incident light intensity is on the order of 100 µs under a 100 Hz operation.

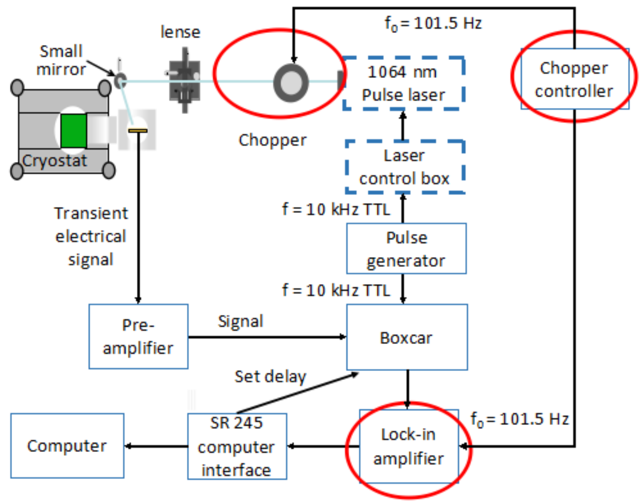

Figure 2. The cryostat-based optically pumped transient electrical signal measurement system using a 1064 nm pulse laser as the excitation source. The dashed blue boxes mark the newly purchased equipment. The signal-to-noise ratio of the measurement is enhanced by the RBC method.

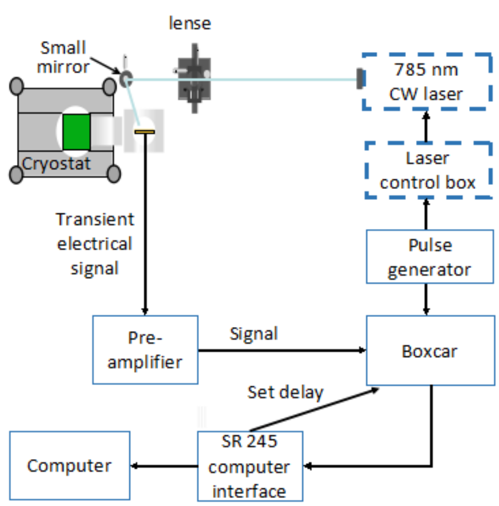

Figure 3. The cryostat-based optically pumped transient electrical signal measurement system using a 785 nm modulated CW laser as the excitation source. The dashed blue boxes mark the newly purchased equipment.

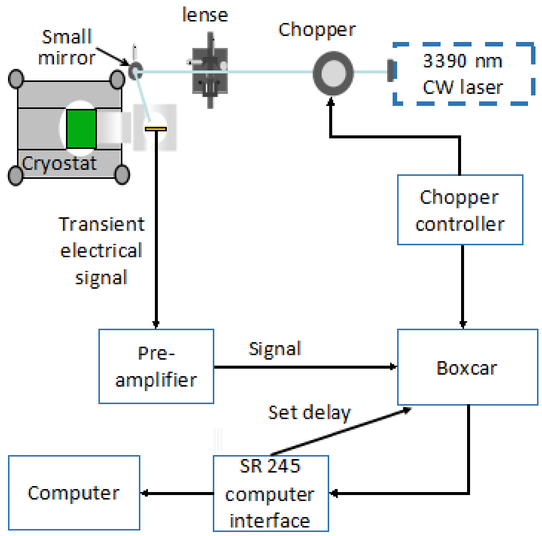

Figure 4. The cryostat-based optically pumped transient electrical signal measurement system uses a 3390 nm CW laser as the excitation source. This laser cannot be modulated electrically so its light beam is modulated by a chopper mechanically. The dashed blue box marks the newly purchased equipment.

3. Probe-station-based ultrafast transient electrical signal measurement system.

A high-speed system with a 1 GHz cut-off frequency was developed based on a low temperature probe station. This probe-station-based system can be used for both the transient open circuit voltage measurement and the transient photocurrent measurement. The probe station uses liquid nitrogen as the coolant and therefore the sample can be cooled down to 77 K. The 1064 nm pulse laser with a short pulse width of less than 1 ns is coupled into the probe station. The transient voltage of the photodetectors is amplified by a preamplifier before it feeds into the high speed boxcar averager. The old slow cable in the probe station with a cut-off frequency of 50 MHz was replaced with a fast cable with a cut-off frequency of 40 GHz. The old pre-amplifier with a cut-off frequency of 1 MHz was replaced with faster pre-amplifiers whose cut-off frequencies are 1 GHz. Overall, this system can achieve a time resolution as short as 1 ns, allowing the measurements of fast transient electrical signals down to 10 ns.

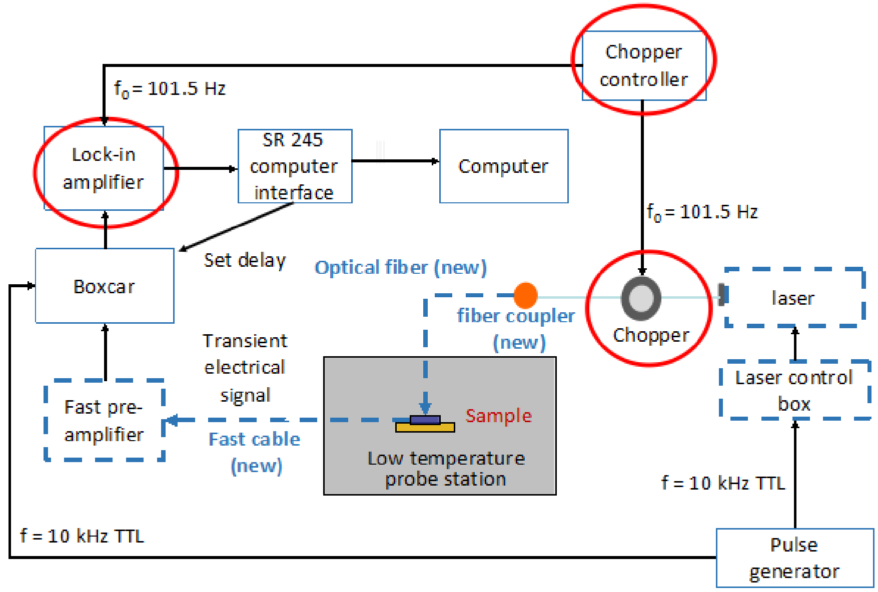

Figure 5. The probe-station-based system for ultra-fast transient electrical signal measurements. The newly purchased equipment is shown in blue dashed boxes. This system can be used for both transient open circuit voltage measurement and transient photocurrent measurement with a time resolution of 1 ns.

The details of the systems for the fast transient optical and electrical signal measurements are summarized in Table 1.

Table 1. Summary of the time resolutions and lowest operation temperatures of the systems for the high-speed transient optical and electrical signal measurements.

No	Measurement type	Cooling system	Laser type	Time resolution	Lowest temperature (K)
1	optical	cryostat	1064 nm pulsed	30 ns	12
2	electrical	cryostat	1064 nm pulsed	1 μs	12
3	electrical	cryostat	785 nm modulated CW	5 μs	12
4	electrical	cryostat	3390 nm CW	100 μs	12
5	electrical	Probe station	1064 nm pulsed	1 ns	77

4. Visible-to-NIR PL system

In addition, a new PL system covering a wavelength range from visible to near infrared (NIR) was built. The new PL system has the capability of characterizing the optical properties of the CdTe materials, which is used for the AFOSR multi-color detector project.

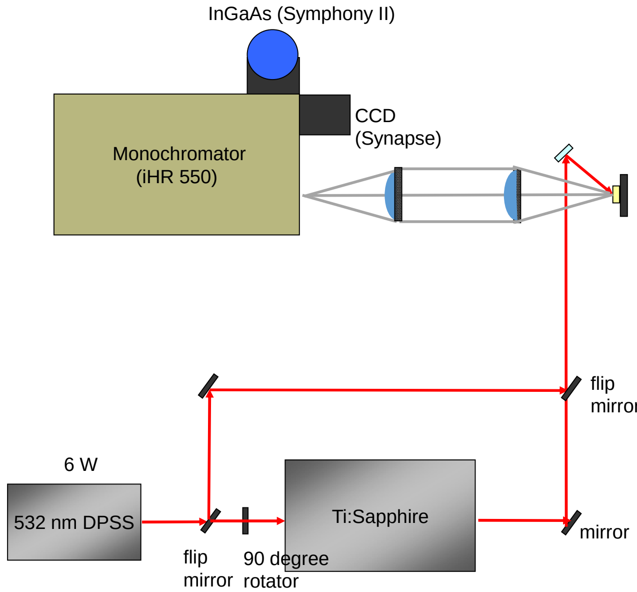

Figure 6. Visible-to-NIR PL system

The new Horiba PL system has the capability of characterizing materials with PL in the wavelength range of 300 nm ~ 1700 nm. The system consists of an iHR550 monochromator, a CCD detector and an InGaAs array detector. The iHR550 monochromator with a focal length of 550 mm enables high resolution spectra measurement. Its unique asymmetric Czerny-Turner design allows for extremely low stray light. With the 3 grating turret, the measurements can be done with the optimal grating within each spectra range. The CCD array detector is thermoelectrically cooled, back illuminated and deep depleted, providing high quantum efficiency in the 300 nm to 1050 nm wavelength range. The InGaAs array detector is liquid nitrogen cooled and has high responsivity and low noise level in the near IR region (from 800 nm to 1700 nm). Combined with the advanced iHR550 monochromator, the system is available for fast PL measurements while maintaining high responsivity and high spectral resolution (0.1 nm for CCD and 0.2 nm for InGaAs detector).

Two lasers are currently used in this system: a 6 W 532 nm Diode Pumped Solid State (DPSS) laser, and a Ti:Sapphire laser. The output power of the Ti:Sapphire laser is determined by the pumping power of the DPSS laser, and typically 0.5 W of power at 800 nm can be achieved with 5 W pumping power. The wavelength of the Ti:Sapphire laser can be continuously tuned from 750 nm to 950 nm.

III. Summary

In order to study the carrier dynamics in InAs/InAsSb T2SL materials and devices, a few experimental systems have been developed. These experimental systems include a time-resolved photoluminescence (TRPL) system, a cryostat-based transient electrical signal measurement system with three available lasers at different wavelengths, and a probe-station-based transient electrical signal measurement system. Additionally, a steady state visible-NIR PL system was built to study the CdTe material for multi-color detector applications.